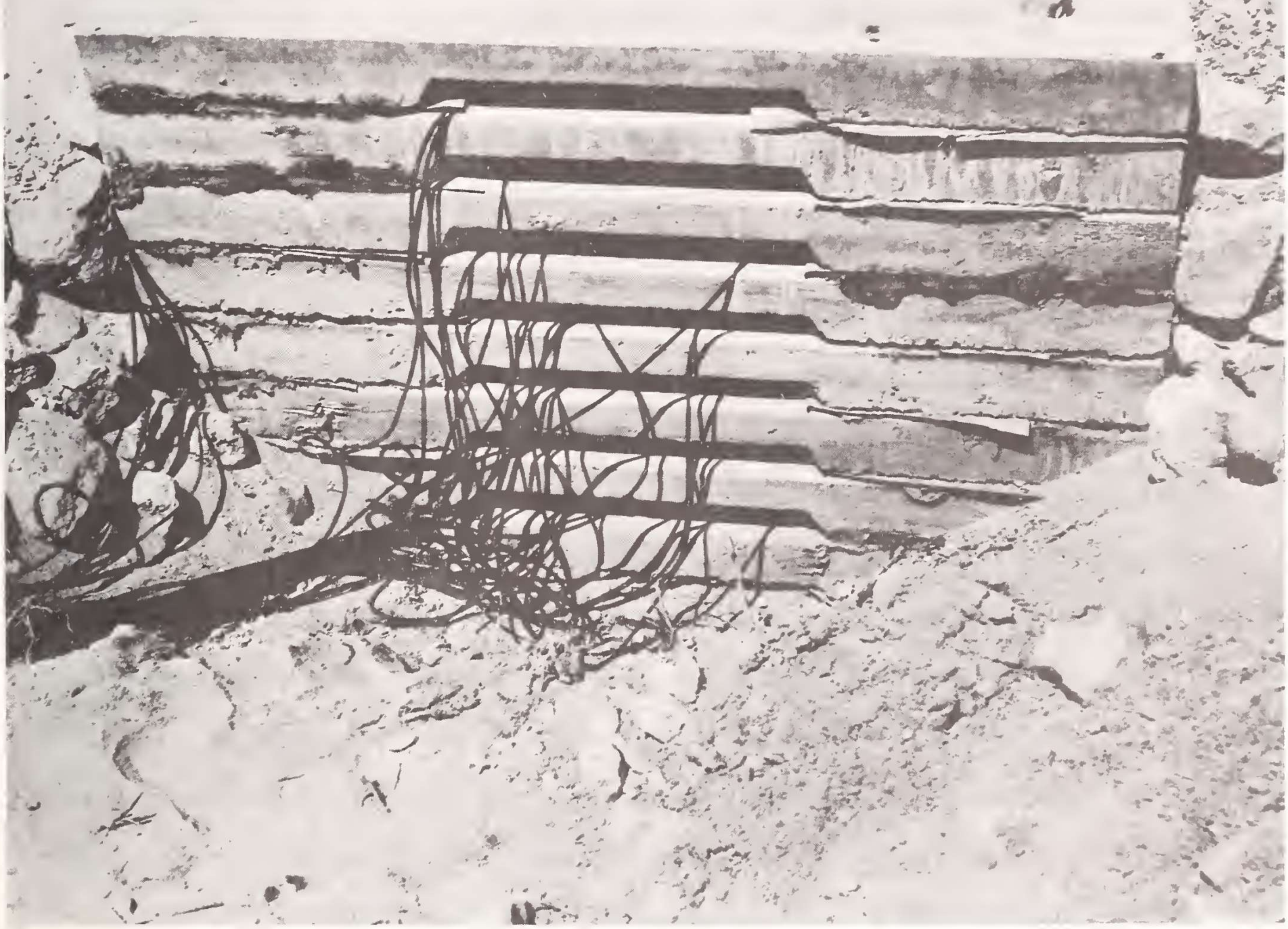
NATIONAL BUREAU OF STANDARDS

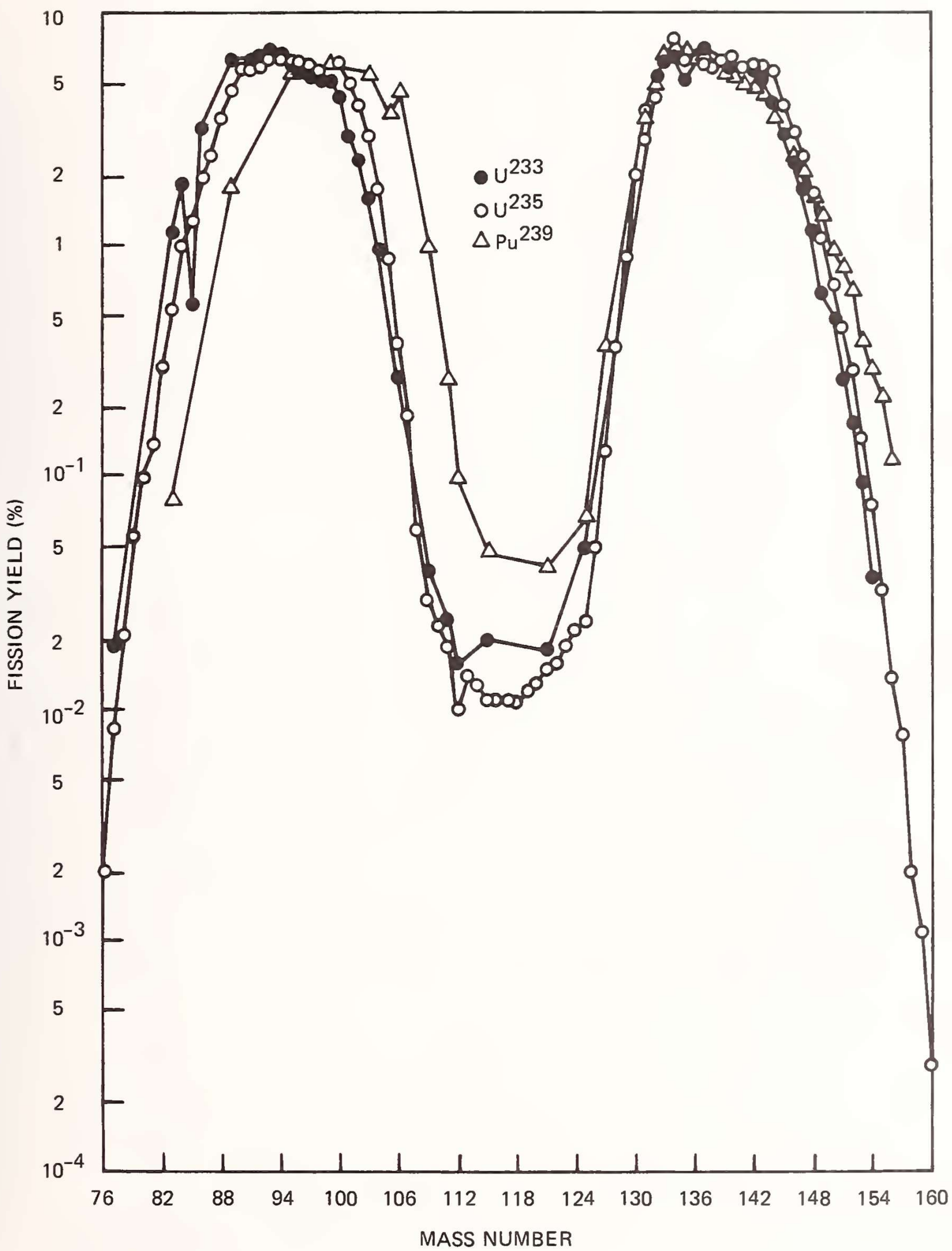
NBS SPECIAL PUBLICATION 570

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Structure Shielding Against Fallout Gamma Rays From Nuclear Detonations



I.4 The multi-slab concrete sandwich for the experiments on penetration of fallout gamma rays, carried out by F. Titus as part of the Plumbob test series [39].



II.1 Yield data for several cases of nuclear fission [2].

Table II.1 Typical chains of beta-ray transitions for several fission fragment mass numbers. The numbers underneath in parentheses give the charge distribution of the fission fragments at the moment of fission, per 10^4 fissions, according to Kochenderfer [9]. Half lives in seconds (s), minutes (m), hours (h), days (d), or years (y) are also in parentheses; these values are from England and Schenter [60].

Mass Number
Yield/10^4 fiss.

89 (472): As(.13s) (.6) → Se(.41s) (57.3) $\xrightarrow{.05}$ n + ^{88}Br; Se(.41s) $\xrightarrow{.95}$ Br(4.5s) (200); Br(4.5s) $\xrightarrow{.09}$ n + ^{88}Kr; Br(4.5s) $\xrightarrow{.91}$ Kr(3.2m) (175) → Rb(15.2m) (38.6) → Sr(52d) (0) → Y(∞)

90 (572): As(.09s) → Se(.55s) (30) → Br(1.6) (180) $\xrightarrow{.12}$ n + ^{89}Kr; Br(1.6) $\xrightarrow{.88}$ Kr(32.3s) (263); Kr(32.3s) $\xrightarrow{.16}$ Rb(4.3m); Kr(32.3s) $\xrightarrow{.84}$ Rb(2.7m) (98.6); Rb(4.3m) $\xrightarrow{.05}$ Rb(2.7m); Rb(4.3m) $\xrightarrow{.95}$ Sr(28.1y) (0); Rb(2.7m) → Sr(28.1y) (0) → Y(2.7d) (0) → Zr(∞)

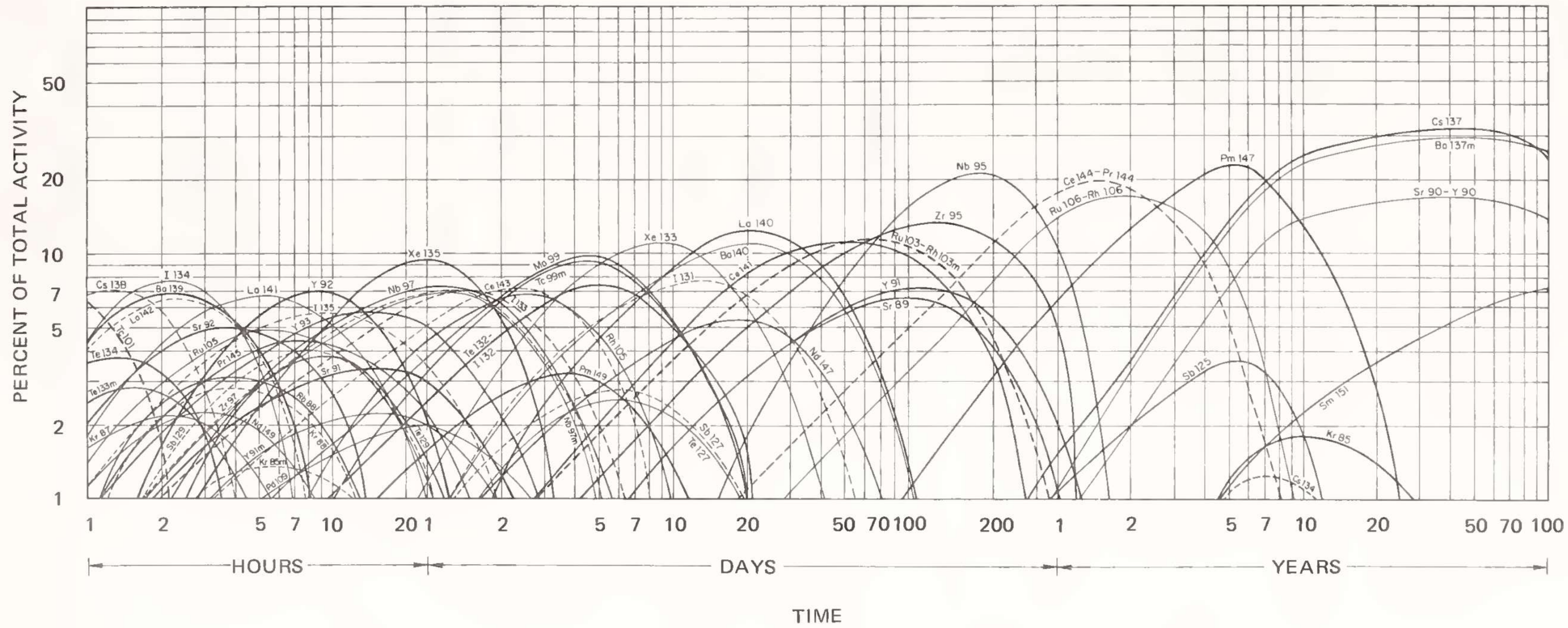
95 (626): Br(.12s) → Kr(.50s) (40.2) → Rb(.36s) (212) $\xrightarrow{.07}$ n + ^{94}Sr; Rb(.36s) $\xrightarrow{.93}$ Sr(.26s) (277) → Y(10.5m) (94.4) → Zr(65.5d) (1.9) $\xrightarrow{.01}$ Nb(3.6d); Zr(65.5d) $\xrightarrow{.99}$ Nb(35d) (0); Nb(3.6d) → Nb(35d); Nb(35d) → Mo(∞)

131 (293): Cd(.12s) → In(.3s) (17.7) $\xrightarrow{.095}$ n + ^{130}I; In(.3s) $\xrightarrow{.905}$ Sn(63s) (97.4) → Sb(23m) (131) $\xrightarrow{.07}$ Te(3.0h) (23.0); Sb(23m) $\xrightarrow{.93}$ Te(25m) (23.0); Te(3.0h) $\xrightarrow{.18}$ Te(25m); Te(3.0h) $\xrightarrow{.82}$ I(8.0d) (.9); Te(25m) → I(8.0d); I(8.0d) $\xrightarrow{.01}$ Xe(12.0d); I(8.0d) $\xrightarrow{.99}$ Xe(∞); Xe(12.0d) → Xe(∞)

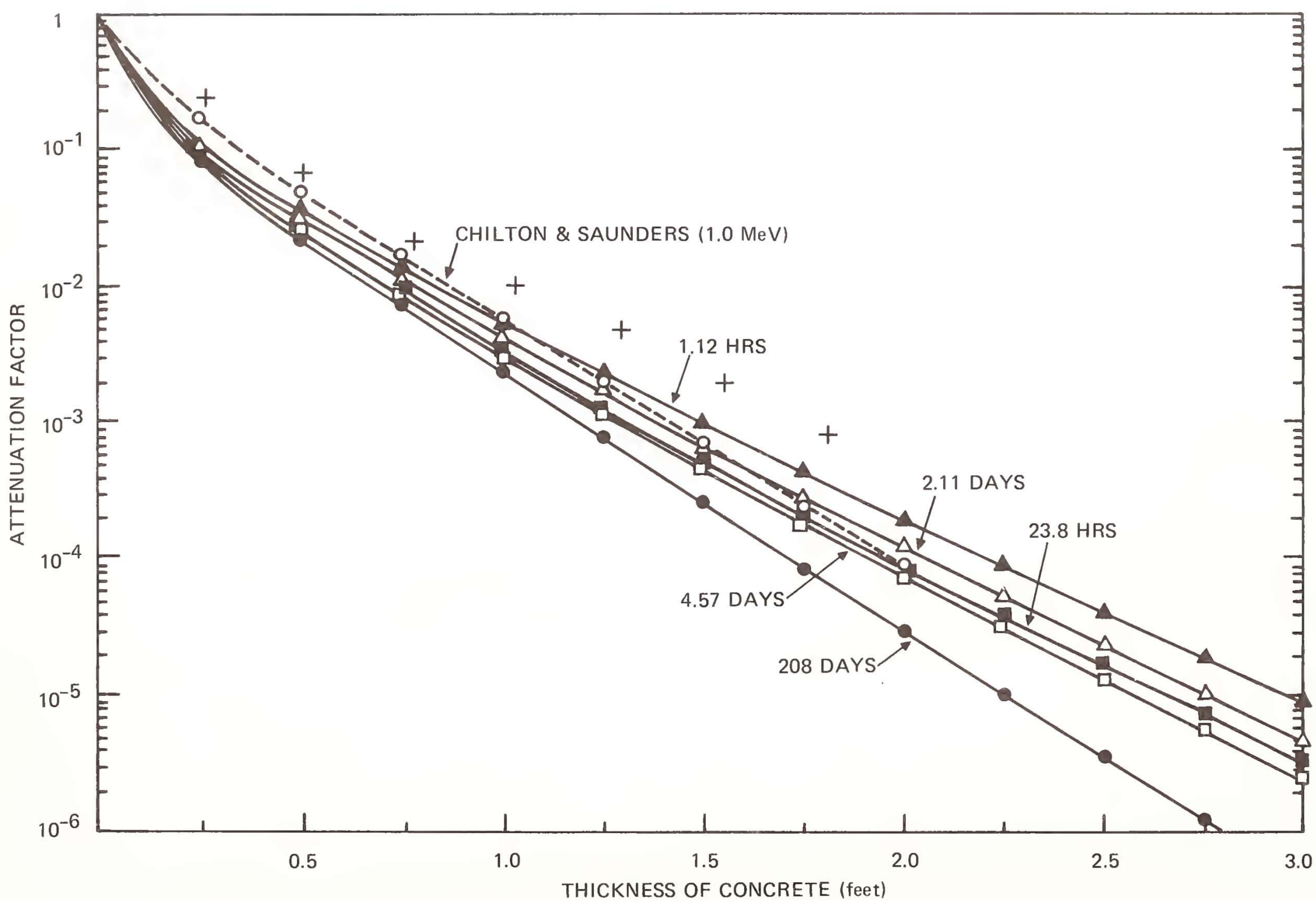
137 (615): Sb(.28s) → Te(3.5s) (46) $\xrightarrow{.005}$ n + ^{136}I; Te(3.5s) $\xrightarrow{.995}$ I(24.6s) (220); I(24.6s) $\xrightarrow{.05}$ n + ^{136}Xe; I(24.6s) $\xrightarrow{.95}$ Xe(230s) (266) → Cs(30.1y) (81.5) $\xrightarrow{.95}$ Ba(153s); Cs(30.1y) $\xrightarrow{.05}$ Ba(∞); Ba(153s) → Ba(∞)

140 (642): Te(.75s) → I(.86s) (28.6) $\xrightarrow{.32}$ n + ^{130}Xe; I(.86s) $\xrightarrow{.68}$ Xe(13.6s) (202) → Cs(63.8s) (296) → Ba(12.8d) (112) → La(40.2h) (3.7) → Ce(∞)

155 (3.26): La(.22s) → Ce(.71s) → Pr(1.9s) (.15) → Nd(26.1s) (.96) → Pm(36.6s) (1.51) → Sm(2.2m) (.62) → Eu(4.8y) (.02) → Gd(∞)



II.4 Principle contributions to the activity of unfractionated fission products from thermonuclear neutron fission of ^{238}U [28].



II.17 Curves give attenuation factor versus concrete thickness for a smooth isotropic plane source emitting various fission spectra [93]. The heavy plus signs lying above the curves give experimental data due to Titus (shot B, 2 hours after detonation) [97].

throughout the cloud. The cloud is subdivided into segments, and each segment is repeatedly assigned a specified particle size and called a wafer. These are transported according to wind patterns and estimated fall rates.

The prototype of the scaling studies was due to C. F. Ksanda and coworkers in 1953 [113] at the Naval Radiological Defense Laboratory (NRDL), whose study was based on fallout patterns from Operation Jangle (1951) which were described by R. K. Laurino and I. B. Poppoff [114]. Results of early scaling studies were incorporated in the 1957 edition of Effects of Nuclear Weapons [12]; but W. W. Kellogg, in his 1957 testimony to Congress, documented the discouragingly poor agreement among different fallout prediction systems at that time [115]. A fallout symposium held in March 1957 concluded that "without a more thorough understanding of the mechanics of the fallout process, from the early stages of the fireball until a major fraction is deposited on the ground, we cannot expect to construct a fallout model that will yield reasonably accurate predictions" [116].

Much early work on fallout models was incompletely published, partially classified, or suited only to some highly specialized application. The 1957 Congressional Hearings are a good source for early results and general approaches, particularly Kellogg's presentation [115], and Schuert's discussion [117]. Unclassified and reasonably complete presentations of particular methods a few years later include A. D. Anderson's paper in 1961 [116] and the 1960 report by Callahan and coworkers [118].

Widespread work on fallout prediction systems in the late 1950's led to a second symposium in September, 1962, at which intercomparisons of many models were discussed on the basis of hypothetical burst conditions previously circulated to interested groups. This conference was fortunately followed up by extensive analysis of 18 of the models, even though many models were still not well documented [119,120]. Comparisons again showed that predictions of different models were very diverse.

A third symposium was held in April, 1966, and was far better focussed on the basic physics problems fundamental to the important processes [121]. By this time it was clear that only a few models would receive extensive additional development and use. In fact, much of the symposium consisted of reports about work on subunits of the DELFIC prediction system, a wafer system intended to satisfy requirements by all the different branches of the Department of Defense, thus superceding a large fraction of the existing models.

In the remaining paragraphs of this section we sketch four systems for calculating fallout intensities and spectra which remain relevant to current applications. These are the WSEG model, a Miller model, the DELFIC model, and a SEER model.

One should be aware throughout this discussion that the intercomparisons of reference [120] have not been fully extended to the more recent models or versions of older models.[21] Further, no systematic study seems to have been made of any model in comparison with data from most of the tests which have been conducted. This is largely because of the state of information about the test detonations, which is fragmentary except for a few cases. But there is also a difficulty of interpretation of differences because of the large number of variables involved.

This problem of pinning prediction systems to adequate, incontrovertible data leads to the opinion that these systems have their main application in hypothetical attack studies, and that they would not be dependable as a sole basis for fallout intensity estimates after a nuclear attack or for operational decisions on which the lives of people near a detonation might depend.

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[21] A step in this direction was taken by C. J. Seery [122], in a paper describing a "TINCAN" model suggested by I. Russell. Sensitivity studies were included, with data on cloud radius, cloud height, particle fall rate, refractory mass fraction, and particle frequency distribution. Comparisons of TINCAN with the other models described here were made.

a. The WSEG Model[22]

Of the scaling models, that of G. E. Pugh and R. J. Galiano is the currently most important because it is used nearly universally in the hypothetical attack studies which attempt to assess damage to this country [119]. In this model the cloud activity is described by a Gaussian distribution whose height and lateral spread are functions of the yield. Neither particle size distribution nor fall rates are explicitly used in this model; and the cloud is not divided into wafers. Instead, there is a carefully specified function of the time after detonation which determines the rate of activity deposition on the ground. A scaling rule changes "time" in this function to downwind distance, by use of an effective wind speed. A crosswind shear dependent on cloud thickness must also be specified.

Dose rate on the ground is specified by the product of separate functions of the downwind and crosswind distances: The crosswind function is a Gaussian, and the downwind function is the product of a falling exponential function of downwind distance with a cumulative normal function.

This model is implemented by a very fast code, clearly suitable to studies which must cumulate the effect of many bursts, when details tend to be unimportant because of effects of superposition.

b. The Miller Model

A scaling approach was developed by Miller in the period 1962-64 based on data from the test shots Jangle 5 and Castle Bravo, and has been described in a 1969 paper [124]. More complex and physical than the WSEG model, it has been used in some damage assessment studies.[23]

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[22] For Weapons System Evaluation Group [123].

[23] A later model (see ref. [125] by C. F. Miller is more empirical and comparable with DELFIC. While Miller's most recent model reflects the state of the art, we prefer to describe here Miller's earlier, more conceptual approach.

The Miller model distinguishes between the stem and the cloud of the mushroom due to a ground burst. The stem generates a high intensity "ridge" downwind, with intensity decreasing laterally. Superimposed on this is the broader cloud fallout pattern carried by the wind to greater distances because of its initially greater altitude. For both stem and cloud, intensities and distances are specified along the pattern centerline as functions of the yield and the wind velocity, and along a line of maximum lateral extent by use also of wind correction and shear factors. Both stem and cloud patterns are then described by contours in the shape of half-ellipses smoothly joined together and in agreement with the centerline and width values. The two components are summed to get the total "intensity", which is identified as a specific detector measurement 3 ft above an extended open area. The result in a simple wind pattern is to reproduce the fallout as a sort of shadow of the mushroom cloud, a characteristic observed with atmospheric nuclear tests.

Particle fall from the stem is assumed to be unaffected by lateral wind shear, but shear is taken into account in a simple way in the description of fallout from the cloud. Wind velocity is assumed to have an average magnitude at all altitudes. Particle concentrations are assumed to be uniform in the original mushroom cloud; but larger particles are assumed to fall from lower altitudes in the stem, and particle concentrations in the stem are assumed to decrease gradually with height. Contributions to exposure are functions of particle size expressed through fall speed; and at any location, the fallout varies between minimum and maximum fall speeds characteristic of the position. This leads to definite times of arrival and cessation of the fallout, and to exoisyre rate as a function of time and position, taking account of fractionation.

c. The DELFIC Model[24]

Beginning about 1965, an effort was instituted by the Defense Atomic Support Agency (now the Defense Nuclear Agency) to develop a single model for all applications. It was intended that this model, called DELFIC, would combine the best features available. But the model would have to be a compromise in many respects and in this regard one more among many systems.

DELFIC consists of five principal modules: Initial Conditions, Cloud Rise, Transport, Particle-activity, and Output-processor.

The "Initial Conditions" module requires yield and height data, together with data on the type[25] and natural particle-size distribution of the soil. It identifies an effective starting time for cloud rise and specifies for that time the average temperature of the nuclear cloud, the total amount of entrained soil material together with the fractions in vapor and condensed phases, and the size-frequency distribution of the soil particles. In constructing the code, it was eventually concluded that the natural size distribution of soil particles could be used except possibly for large-yield detonations. Most other output data are determined by scaling relationships based on test measurements and on estimates of energy partition among different processes.

The "Cloud Rise" module is based on a modified version of a model developed by I. O. Huebsch [128-130]. There are two stages of the calculation. In the first, the cloud is treated as a whole, with uniform density and temperature, water and water vapor conditions, and turbulent kinetic energy density. Mass of the cloud can change due to entrainment and particle fallout and these affect the dynamic behavior. Vertical wind shear is accounted to increase entrainment

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[24] Department of DEfense Land and Fallout Interpretive Code. The Monterey Symposium Report [126] has been superceded by [127] and should be used with caution.

[25] In general, soil types can be classified as either siliceous (melting temperature near 1673 K) or calcareous (melting temperature near 2887 K).

through changes in shape which are not otherwise considered. Cloud volume and mass are related through assumption of an expanding oblate spheroidal shape.

In the second part of the Cloud Rise module, particle wafers are identified at the initial time by subdividing the cloud into horizontal disk segments and assigning to each segment a set of wafers, each with characteristic particle size interval. The wafers are then subdivided into horizontal segments to permit horizontal distortion; the upper and lower wafer boundaries are followed separately to take account of verticle stretching. The full set is then followed in space through the rise processes, as position and shape are modified by the forces effective. The resulting output is a set of distorted wafers distributed vertically and suitable for the transport process. Wafers with different particle size intervals will be at different heights after cloud rise.

The "Atmospheric Transport" module utilizes an atmosphere divided into sub-volumes, each with properties uniform throughout. Large cells are used to take account of region of macro-meterorological phenomena, while small cells can be used to take account of local circulation systems such as those affected by topographical features such as a mountain. With this approach, wind-patterns characteristic of certain regions and having considerably complexity, including vertical components, can be utilized. Standard settling rates are used based on formulae for spheres of different sizes. Wind effects and fallout <u>during</u> cloud rise are taken into account.

The "Particle Activity" module distributes activity with particle size according to a modified version of Freiling's radial-distribution model; that is to say, volatile chains are assumed to condense on surfaces while refractory chains are distributed through particle volumes, as previously discussed. Fractionation is thus taken into account and predictions for specific types of

nuclides can be made as well as for total activity. Induced activities are also included. Dose rates 3 ft above a smooth plane ase determined according to the local spectrum.

The "Output Processor" module sets up the format for the various selections of output data of greatest interest [131].

d. SEER Models[26]

While DELFIC was developed to be as realistic as the state-of-the-art permitted, this same requirement implies long and comparatively expensive runs. Other requirements for fast and cheap computations led to attempts to develop simplified versions of DELFIC, in competition with the WSEG Model but hopefully giving results more nearly equivalent to those of DELFIC for the intended applications. The SEER Models (Simplified Estimation of Exposure to Radiation) are of this type, with running times for a single case 1/50 to 1/100 that of DELFIC, and with rather good agreement for sample cases.

To achieve short running times assumptions such as the following are used: Starting point at stabilized cloud, with parameters from DELFIC-generated library, wind profiles constant in time and space, a log-normal particle size distribution, precalculation of falling times for deposition of cloud wafers, uniform cloud, and use of standard function types to represent lateral distributions relative to the "hot-line" for a cloud layer.

2. Continuing Problems of Fallout Phenomena

Research into different aspects of fallout phenomena has been at a low level for many years. This is due in part to the lack of new data; but much research has been cut back despite the possibility of significant progress. Hence we sketch here briefly the status of some representative problem areas. As our model we use a similar discussion in ref. [133], which was divided into the four categories which we use below. See also [13], Appendix VII.

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[26] See reference [132].

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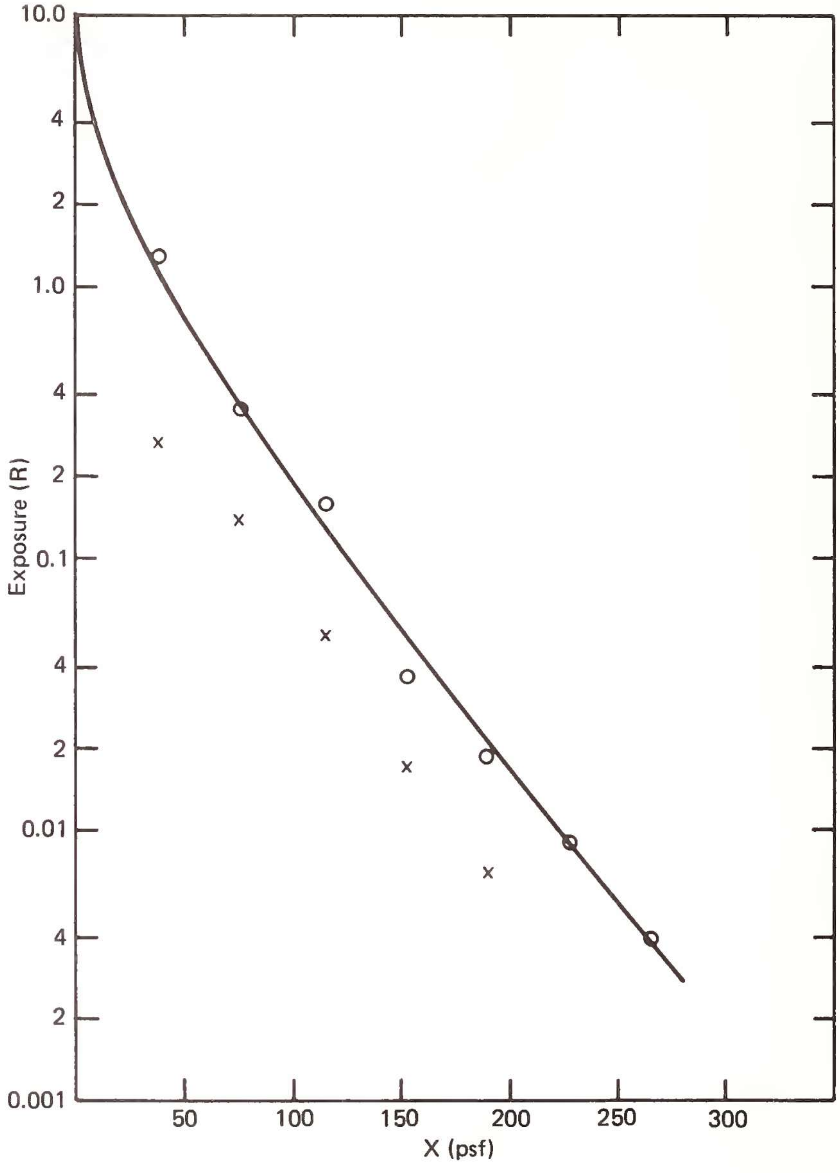

VIII.1 Comparison of Experimental and Calculated Exposures from Fallout Radiation as a Function of Depth in a Concrete Medium.
○ , X Experimental, Titus [1]; —— Calculated L(X) (x10) (Fig. V.12).

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